

Determination of Tsukuba VLBI Station post-Tohoku Earthquake Coordinates using VieVS

Niko Kareinen, Minttu Uunila

Aalto University Metsähovi Radio Observatory

Contact author: Niko Kareinen, e-mail: nkareine@kurp.hut.fi

Abstract

We determine the new coordinates for the Tsukuba VLBI station, which was affected by the Tohoku earthquake on March 11, 2011. A total of 31 IVS-R1 sessions dating from 2011-01-03 to 2011-09-12 were pre-processed with Vienna VLBI Software (VieVS v. 1d), removing low quality data, clock breaks, and outliers. A priori coordinates from NGS file headers were used for TSUKUB32 in order to exclude the station from NNT/NNR conditions. After the initial VieVS analysis, a visualization tool was written in Matlab to analyze the possible change in the coordinates and to detect possible low quality measurements missed by initial processing. The visualization tool has a functionality to transform the ECEF coordinates and errors acquired with VieVS to the local tangent plane of Tsukuba for better comparison possibilities. The visualization tool was written in a way that it could be added in the next version of VieVS as a general time series tool. The time series demonstrated a clear shift in the coordinates before and after the quake. A co-seismic shift of $(X,Y,Z) = (-36.9, -54.7, -2.4)$ was detected in ECEF and $(E, N, U) = (65.6, 2.0, -6.9)$ cm in ENU. Also post-seismic movement was clearly seen in the time series.

1. Introduction

The proximity of the Tsukuba VLBI station to the epicenter of the 11 March 2011 magnitude 9 M_w earthquake in Tohoku, Japan offered a chance to study and model the subsequent change in the station position using VLBI observations from Tsukuba. Out of the multiple VLBI analysis software available, Vienna VLBI Software (VieVS [1]) offered a possibility both to analyze the effect of the earthquake and to validate and compare the findings with results obtained with other analysis software and space geodetic techniques (e.g., GPS).

2. Objectives and Strategy

We set out to determine the co- and post-seismic movement of the Tsukuba VLBI station by analyzing VLBI observations with VieVS and in the process to create an efficient VieVS-compatible time series plotting tool to visualize the results. The Matlab visualization tool was written in such a way that it could be utilized as a more general utility with VieVS in the future.

To determine the movement of the station, 24-hour sessions containing TSUKUB32 were selected for analysis. In order to cover an adequate time span before and after the main shock, initially a time span of 271 days from 2011-01-01 to 2011-09-30 was selected. During the time period, TSUKUB32 participated in a total of 44 24-h sessions. For consistency the IVS-R&D, APSG, and CONT11 sessions were excluded from the analysis. In addition to this, the NGS card of the R1 session on September 6th caused a program error in VieVS and was thus excluded from processing. Consequently a total of 31 R1-sessions were included in the analysis, covering a time

period from 2011-01-03 to 2011-09-12.

3. Analysis Conditions and Procedure

The selected sessions were analyzed individually using VieVS version 1d. The modeling options used in the analysis are presented in Table 1.

Table 1. Modeling options for R1 sessions.

Parameter	VieVS modeling option
TRF	VTRF2008
CRF	ICRF2
Ephemeris	JPL 421
A priori EOP	IERS C04 08
Precession/Nutation	IAU2006/2000
Tidal ocean loading	FES2004
Pole tide	Cubic (IERS2010)
Mapping function	VM1

Each session was analyzed individually to get a first solution to inspect stationwise residuals in order to remove possible sources of errors, such as clock breaks, bad baselines, and problems with one or more stations. After creating initial OPT-files for every session individually, the main solution was applied to inspect the effect of the corrections by examining the changes in the standard deviation of unit weight of the main solution.

Tsukuba was excluded from the No-Net-Translation/No-Net-Rotation (NNT/NNR) conditions to prevent the movement of Tsukuba from affecting the observation network. For consistency, Tsukuba was also removed from the conditions for all epochs before the earthquake. The most efficient way to impose NNT/NNR conditions in VieVS is to edit the TRF and to remove the station. Thus, the a priori station coordinates for Tsukuba before and after the earthquake were read from the NGS file headers. In the case of VTRF2008, the station coordinates for TIGOCONC were also only valid until the 2010 Chile earthquake, and it was automatically removed for all epochs in the analyzed sessions. However, after initial processing it was evident that TIGOCONC had noisy data, and removing the station by excluding it in the OPT-files decreased the error of the main solution significantly. The parameters estimated in the main solution are presented in Table 2.

4. Results

4.1. ENU Coordinates from IVS-R1 Sessions

The single session analysis results for the station position of TSUKUB32 in local East, North, Up (ENU) coordinates are displayed in Figure 1. Corresponding co-seismic changes both in XYZ and ENU as well as adjusted VTRF2008 coordinates are presented in Table 3.

¹Excluding TSUKUB32

Table 2. Estimated parameters and constraints used with R1 sessions in VieVS.

Estimated parameters and constraints for R1 sessions		
Parameters	Interval	Constraint
Clock parameter	60 min	Relative 0.5 $\frac{ps^2}{s^2}$
ZWD	30 min	Relative 0.7 $\frac{ps^2}{s^2}$
NGR/EGR	360 min	Relative 2 $\frac{mm}{day}$
Station TRF coordinates (X,Y,Z)	One offset/session	NNT/NNR ¹

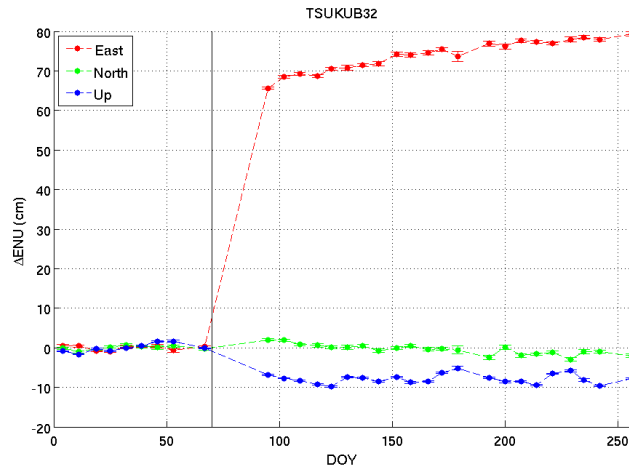


Figure 1. ENU coordinate estimates for Tsukuba from IVS-R1 sessions.

Table 3. Co-seismic displacement of Tsukuba in XYZ and ENU coordinates based on IVS-R1 sessions.

	ΔX	ΔY	ΔZ	ΔE	ΔN	ΔU
Co-seismic displacement (cm)	-36.9	-54.7	-2.4	65.6	2.0	-6.9
	X		Y		Z	
VTRF2008 coordinates adjusted for co-seismic displacement (m)	-3957409.174		3310228.926		3737494.726	

The co-seismic movement of the station was most prominent in the East direction with smaller movements in the North and downward directions. A noticeable post-seismic movement can be seen especially in the most affected East direction. The initial position estimate is influenced by the 27-day break in the observations following the earthquake with the station returning to observing duties on 2011-04-04. While the post-seismic movement to the East and North is relatively stable, the Up-direction estimate exhibits more significant unstable variations, particularly between June and September. This could be due to problems in the analysis of individual sessions, as the values of the standard deviation of unit weight of the main solution are somewhat larger in some of the

sessions during the June-September time period.

4.2. Comparison to GPS Data

The obtained VLBI displacements are in relatively good agreement with other results (e.g., [2]). When compared to GPS data of the IGS-site TSKB [3], from the first VLBI session after the quake onwards, the post-seismic movement of TSUKUB32 agrees comparatively well with the GPS results. RMS values of VLBI-GPS drift rates in ENU after the earthquake are smaller with the East and North coordinates more stable in comparison to the Up direction. In Figure 2 the relative drift rates of the post-seismic movement within the VLBI observation period is displayed.

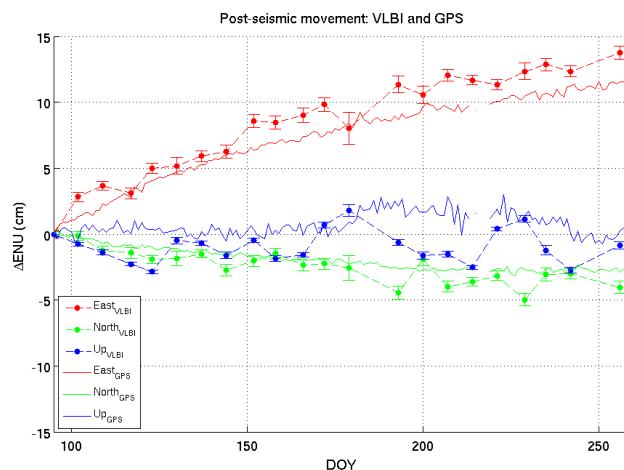


Figure 2. Relative post-seismic movement derived from GPS and IVS-R1 sessions.

5. Discussion

Based on the analysis the post-seismic movement of TSUKUB32 continues towards the eastern direction of main co-seismic movement. For future work more sessions should be added to the analysis to get a better picture of the relaxation rates. The validation of the results could be made more comprehensive by comparing the results to those of the other VLBI analysis software, such as CALC/SOLVE. Further research could be performed by modelling the post-seismic movement in more detail to get improved a priori estimates with the co-seismic VTRF2008 coordinates by analyzing the effect of the adjusted station coordinates with Intensive sessions.

Acknowledgements

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References

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- [2] <http://www.spacegeodesy.go.jp/vlbi/en/earthquake2011/index.html>
- [3] <http://garner.ucsd.edu/pub/timeseries/measures/>